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UNCLASSIFIED

7th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 14–18, 1999

Low temperature scanning tunneling spectroscopy of different individual impurities on GaAs (110) surface and in subsurface layers

N. S. Maslova†, V. I. Panov†, V. V. Rakov†, *S. V. Savinov*†, A. Depuydt‡ and C. Van Haesendonck‡

† Chair of Quantum Radio Physics, Moscow State University,
119899 Moscow, Russia
‡ Laboratorium voor Vaste-Stoffysica en Magnetisme,
Katholieke Universiteit Leuven, B-3001 Leuven, Belgium

In present work we would like to present the results of low temperature STM and STS investigations of (110) surface of GaAs monocrystals doped with impurities of different kind.

All the experiments were performed using home build low temperature STM with sample cleavage mechanism [1]. Monocrystal GaAs samples with different dopants were cleaved in situ after cooling down to liquid helium temperature therefore exposing clean (110) plane. In our experiments we have used GaAs crystals doped with Te and double doped (compensated) with Si and Zn. To the best of our knowledge STM investigation of double doped samples were performed for the first time.

The most striking observations can be summarized as following. In STM images donor impurities in GaAs such as Te and Si looks like rather weakly localized circular features with diameter approximately 4 nm (Figs. 1, 2). STM image of acceptor impurity, such as Zn, has more complicated structure with both both strongly and weakly localized parts

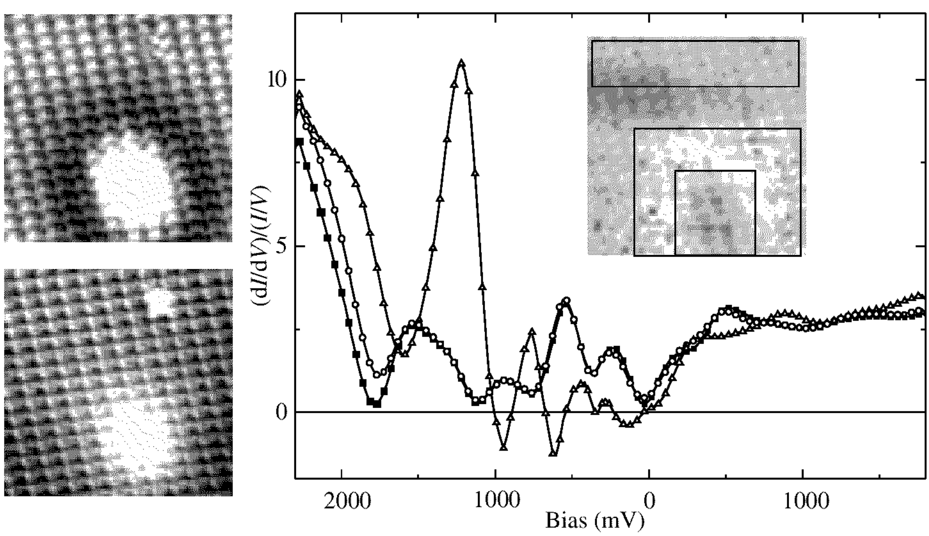

Fig. 1. Tunneling conductivity spectra near Te atom on (110) GaAs surface at temperature 4.2 K. Insert depicts the slice of 40 by 40 tunnelling conductivity curves array taken at -2 V. Each curve is the result of averaging over surface area which is marked by numbers. STM images of surface area 5.8×5.8 nm in size where spectroscopic data was acquired at sample bias: a) -1.5 V; a) $+1$ V.

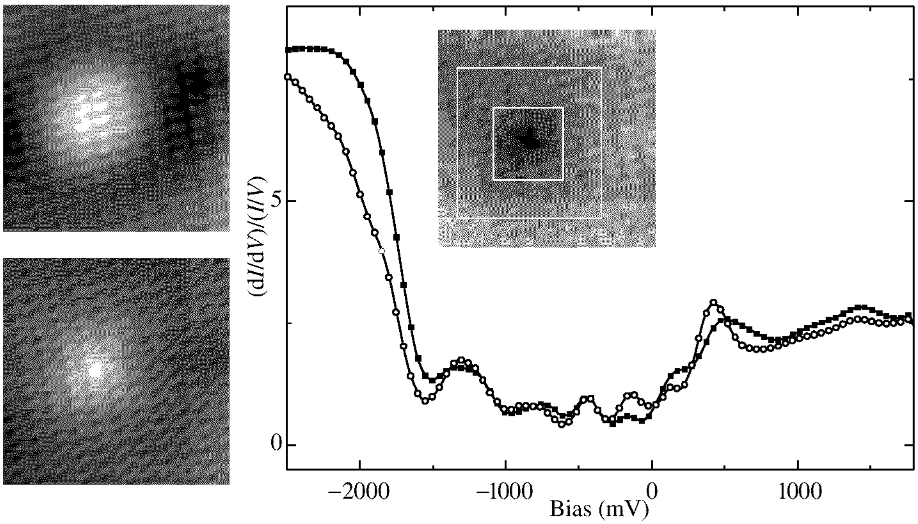

Fig. 2. Tunneling conductivity spectra near Si atom on (110) GaAs surface at temperature 4.2 K. Insert depicts the slice of 40 by 40 tunnelling conductivity curves array taken at −2 V. Each curve is the result of averaging over surface area which is marked by numbers. STM images of surface area 5.8×5.8 nm in size where spectroscopic data was acquired at sample bias: a) −1.5 V; a) +1 V.

and localization radius of about 2 nm (Fig. 3). For negative sample bias donor impurities are seen as a round hillocks surrounded by circular depression, which can be ascribe to the presence of charge density oscillations (Friedel oscillations) [2]. For positive sample bias the corrugation height is smaller and charge oscillations are absent. Donor impurities behave in the same way when they are located in the first or in up to fourth subsurface layer [3].

In general there is no direct evidence in which layer doping atom is located, at the same time symmetry arguments can be used. It was shown that Zn atoms on GaAs surface produces triangle like features. That is why we ascribe defect in Fig. 3 to the Zn atom located on the surface. In opposite to donor atoms, STM image of Zn acceptor is seen as round hollow feature at positive sample bias and as triangle like hillock surprisingly surrounded by round depression. At the same time STM image of Zn atom located below the surface strongly depends on the depth. In general case STM/STS images of impurities in GaAs matrix depends on the depth below the surface, i.e. the number of surface-subsurface layers the impurity is located in, which can be ascribed to different spatial structure of selfconsistent potential caused by induced impurity and/or STM tip charges [4].

Analyzing our results of STM/STS investigations of diferent doping atoms we found out some general similarities in behavior of tunneling conductivity spectra. STS images of all impurities show shift of gap edges as well as changes in semiconductor gap width. We ascribe the observed results to charge induced band bending caused by localized charges on the impurity and/or on the STM tip apex [5]. Tunneling conductivity curves measured above all types of impurities (despite of their positive/negative charge) reveal peaks inside the fundamental band gap in the range from −1.2 V to −1.5 V, near the valence band edge. We suppose that this behavior of tunneling conductivity is also connected with Coulomb interaction of localized charges which shifts impurity levels towards gap edge where tunneling current grows most rapidly with tunneling bias resulting in strong selfconsistent

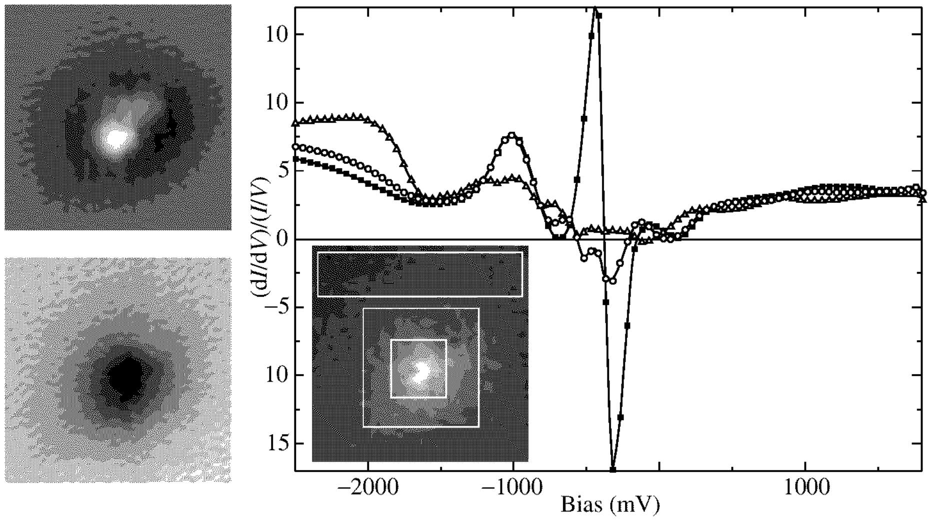

Fig. 3. Tunneling conductivity spectra near Zn atom on (110) GaAs surface at temperature 4.2 K. Insert depicts the slice of 40 by 40 tunnelling conductivity curves array taken at −2 V. Each curve is the result of averaging over surface area which is marked by numbers. STM images of surface area 5.8×5.8 nm in size where spectroscopic data was acquired at sample bias: a) −1.5 V; a) +1 V.

changes of localized charge.

For acceptor impurities there are as positive peaks as negative dips on tunneling conductivity curves in the range from −.2 V to −1 V. This is the bright demonstration that tunneling conductivity is not proportional to the sample local density of states in the presence of localized states. We suppose that charge effects can lead to non-monotone dependence of impurity level energies on applied bias voltage, which results in negative tunneling conductivity. Negative slope of $I-V$ curves can be caused by switching on and off of resonant channels connected with impurity localized states. The energy of such states depends on the value of induced charge, localized in tunneling junction area, which in turn depends on tunneling bias [6]. Thus changes in voltage, applied to the junction, can drive localized state to and out of resonance during $I-V$ dependence measurement.

Acknowledgements

The work in Moscow has been supported by the Russian Ministry of Research (Surface atomic Structures, grant 95-1.22; Nanostructures, grant 1-032) and the Russian Foundation for Basic Research (RFBR, grants 96-0219640a and 96-15-96420). The work at the KU Leuven has been supported by the Fund for Scientific Research–Flanders (FWO) as well as by the Flemish Concerted Action (GOA) and the Belgian Inter-University Attraction Poles (IUAP) research programs. The collaboration between Moscow and Leuven has been funded by the European Commission (INTAS, project 94-3562).

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